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Robust Color Image Watermarking Technique Using DWT and Homomorphic based SVD

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Abstract

This paper presents a robust hybrid image watermarking technique using Discrete Wavelet Transform (DWT) and Singular Value Decomposition (SVD). The DWT is utilized to divide the image into non-overlapping bands. The reflectance component of the low-frequency sub-band (LL) is extracted using homomorphic transform for each color (red, green, and blue). The watermark embedding is performed using SVD on the reflectance component of the LL sub-band. The results of the proposed watermarking technique are compared with some state-of-the-art techniques. The comparison test is performed on images with different resolutions. It is based on visualization to detect any degradations in the watermarked image, Peak Signal-to-Noise Ratio (PSNR) of watermarked image, and Normalized Correlation (NC) of extracted watermark.

Keywords: *Watermarking, Discrete Wavelet Transform (DWT), Discrete Cosine Transform (DCT), Singular Value Decomposition (SVD), Homomorphic transform.*

Nomenclature

DWT	Discrete Wavelet Transform
DCT	Discrete Cosine Transform
SVD	Singular Value Decomposition
MSE	Mean Squared Error
PSNR	Peak Signal to Noise Ratio
NC	Normalized Correlation

1. Introduction

In recent years, information technology, digital data, and multimedia have been easily duplicated, manipulated, and distributed. So, it is very important to have copyright protection to save owners copyrights. There are several protection techniques, one of them is watermarking. Watermarking technology is the process of hiding an image called watermark or label into original digital data (image, video or audio) [1]. Watermarked images must be robust enough to survive attacks [1]. Watermarking techniques can be classified into two categories; spatial domain and transform domain [1]. Several techniques of transform domain watermarking are discussed in this paper.

One of these techniques is the DWT [3,5,9]. It is based on dividing the image into four non-overlapping bands; approximation sub-band (LL), horizontal sub-band (LH), vertical sub-band (HL), and diagonal sub-band (HH) [3,5,6,9].

Another widely-used technique of transform domain watermarking is the Discrete Cosine Transform (DCT) [11-16]. This transform is used to convert spatial domain image into discrete transform domain [14]. Another widely-used technique of transform domain watermarking is SVD [10,11]. It is an effective numerical analysis tool used to analyze matrices. The SVD transformation divides the matrix into three matrices with the same size of the original matrix; two orthogonal matrices and one diagonal matrix [9]. Then, the watermark is embedded in the diagonal matrix [6,8-10,16-18].

Another domain used for watermarking is the homomorphic domain [9]. It is based on image intensity represented as light illumination and reflectance of the image. Illumination is approximately constant and reflectance is variable from image to image. Thus, the reflectance of the image is used to perform the watermarking process. It must be noted that the SVD technique is utilized for avoiding the redundancy resulting from the existence of two components of the image in the homomorphic domain [9].

Hybrid techniques are widely used for watermarking. This can be accomplished by combining two or more techniques to achieve better results.

One of these hybrid techniques is the DCT-DWT [14]. It is based on dividing the RGB color image into three matrices (red, green and blue). The DCT is implemented on each color. Watermark embedding is performed on the LL sub-band by utilizing the DWT to divide the DCT domain into four sub-bands for each color [14-16].

Another hybrid technique is the DWT-SVD [2]. It is based on utilizing the DWT to divide the image into four sub-bands. The LL sub-band is divided into three matrices (red, green and blue). Watermark embedding is performed by

applying the SVD on each color of the LL sub-band [2,6,9,18].
The main aim of this paper is presenting a hybrid technique to achieve robust watermarking based on [1]. The rest of this paper is organized as follows. Section 2 gives a literature review. The evaluation metrices are shown in section 3. Section 4 discusses the proposed technique. The simulation results are illustrated in section 5. Section 6 presents the conclusions followed by the more relevant references.

2. Literature Review

Surveying the literature there are three main techniques most commonly used in color image watermarking: Discrete Wavelet Transform (DWT) [3-5,9], Discrete Cosine Transform (DCT) [6,9,12,15] and Singular Value Decomposition (SVD) [8-10,17]. Hybrid techniques are widely used in watermarking. There are two main hybrid techniques most commonly used DCT-DWT [7,13-15] and DWT-SVD [2]. This paper is the extended paper from conference paper [1].

Discrete Wavelet Transform (DWT)

Wavelet transform is an information processing method; it has been widely used in many fields including image processing. The DWT divide an image into four non-overlapping bands. These bands are calculated in different frequencies [9]. Figure 1 shows the four sub-bands; approximation sub-band (low frequency LL), horizontal sub-band (high frequency LH), vertical sub-band (high frequency HL), and diagonal sub band (high frequency HH). Figure 2 show the low pass and high pass analysis filter h[-m], g[-m] [3-5,9].

LL	LH
HL	HH

Figure 1. The DWT sub-bands.

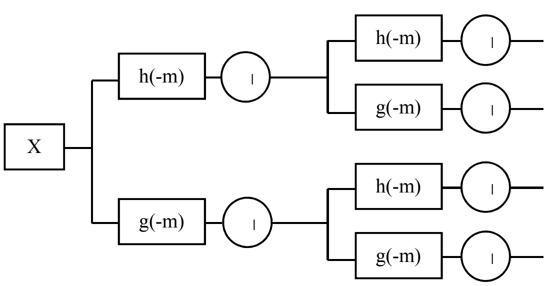


Figure 2. Two dimensional decomposition using the DWT.

Discrete Cosine Transform (DCT)

Discrete Cosine Transform (DCT) is a standout amongst the most well known orthogonal change strategies utilized as a part of picture preparing. High vitality compaction property of DCT is the reason. In watermarking, this property helps in choosing the area in picture to insert the watermark with most robustness [6]. DCT divides aircraft carrier signal into three frequencies bands namely low, middle, and heights frequency bands. It is frequency orbit watermarking technique as watermark is embedded into one of these three bands, carrier signal pixel are not modified directly [12].
Two dimension discrete cosine transform 2D-DCT is defined as [7]

$$F(jk) = a(j)a(k)\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} f(m,n)\cos\left[\frac{(2m+1)j\pi}{2M}\right]\cos\left[\frac{(2n+1)k\pi}{2N}\right] \qquad (1)$$

Inverse transform 2D-IDCT is defined as [7]

$$f(mn) = \sum_{i=0}^{M-1}\sum_{j=0}^{N-1} a(j)a(k)F(jk)\cos\left[\frac{(2m+1)j\pi}{2M}\right]\cos\left[\frac{(2n+1)k\pi}{2N}\right] \qquad (2)$$

Where $0 \le j \le M-1$, $0 \le k \le N-1$,

$$a(j) = \begin{cases} \frac{1}{\sqrt{M}}, & j = 0 \\ \sqrt{\frac{2}{M}}, & 1 \le j \le M-1 \end{cases} \text{ and } a(k) = \begin{cases} \frac{1}{\sqrt{N}}, & k = 0 \\ \sqrt{\frac{2}{N}}, & 1 \le k \le N-1 \end{cases}$$

Singular Value Decomposition (SVD)

SVD is an effective numerical analysis tool used to analyze matrices. The SVD transformation matrix divides the matrix into three matrices with the same size of the original matrix. Then SVD of A is defined as:

$$A=USV^T \qquad (3)$$

Where U and V are orthogonal matrices and S is a diagonal matrix. The entries in these diagonal matrices are called singular value of the matrix A. Applying this technique in RGB color images requires image color separation into three matrices red, green and blue. Implement the SVD watermarking in each matrix and finally reconnect these three matrices given the final watermarked color image [9]. For embedding a watermark into host image, the SVD is performed onto the host image as in (3). The watermark is added to the S matrix of the original matrix as:

$$D=S+kW \qquad (4)$$

SVD performed as a new matrix:

$$D = U_w S_w V_w^T \qquad (5)$$

The watermarked image is:

$$A_w=US_wV^T \qquad (6)$$

For extract watermark the watermarked image is:

$$A_w^* = U^* S_w^* V^{*T} \qquad (7)$$

The matrix include watermark is computed:

$$D^* = U_w S_w^* V_w^T \qquad (8)$$

It's possible to corrupt watermark [6,8,9,17,18]

$$W^*=(D^*-S)/k \qquad (9)$$

The hybrid technique (DCT-DWT)

The hybrid technique DCT-DWT is based on utilized the DWT to divide DCT domain into four sub-bands [14]. The RGB color image is divided into three matrices (red, green and blue). The DCT domain is extracted by applying the DCT for each color. Embedding watermark is done on sub-band LL by utilize DWT to divide the DCT domain into four sub-bands for each color [14-16].

The hybrid technique (DWT-SVD)

The hybrid technique DWT-SVD is based on utilized the DWT to divide image into four sub-bands and then applying SVD into diagonal sub-band (LL) [2]. The DWT is utilized to divide image into four sub-bands. The sub-band LL is divided into three matrices (red, green and blue). Embedding watermark is done by applying SVD for each color of sub-band LL [2,6,9,18].

3. Evaluation Matrices

All tests were performed using an Intel® core™i5 CPU M450 @2.4GHz with 6GB Memory and running Windows 7 64-bit operating system and using MATLAB 8. All the images used are 512×512 colored JPEG images. There are five main tests to determine the performance of a watermarking technique. Visually test to determine the invisibility of watermark and any degradation in quality or colors in the watermarked image compared to original image. The Peak Signal-to-Noise Ratio (PSNR) of the watermarked image and the Normalization Correlation (NC) for the extracted watermark are calculated. Applying attacks on the watermarked image then extracting the watermark and repeating the NC tests again after attacks. Calculate the CPU time for embedding algorithm.

PSNR can be calculated by [9]

$$MSE = \frac{1}{\text{M}\times\text{N}} \sum_{x=0,y=0}^{M-1,N-1} (A_w(x,y) - A(x,y))^2 \quad (10)$$

$$PSNR\ (DB) = 10 \log_{10} \frac{255^2}{MSE} \quad (11)$$

where A is original image, A_w is watermarked image and M, N size of original and watermarked image. NC calculate given by [9]

$$NC = \frac{W^*.W}{\|W^*\|.\|W\|} \quad (12)$$

where W is original watermark and W^* is extract watermark.

4. The Proposed Watermarking Technique

The proposed technique presented here is DWT-homomorphic based SVD. The DWT is utilized to divide image into four non-overlapping bands. The reflectance components of the sub-band LL is extracted using homomorphic transform for each color (red, green and blue). Embedding watermark is done by applying the SVD on reflectance components of the sub-band LL. The sub-band (LL) intensity can be represented as:

$$f\_LL(n_1,n_2)= i(n_1,n_2)r(n_1,n_2) \quad (13)$$

where $i(n_1,n_2)$ is the light illumination and $r(n_1,n_2)$ is the reflectance of the object to be sub-band imaged. The homomorphic transform is performed.

$$\ln [\ f\_LL(n_1,n_2)]= \ln[i(n_1,n_2)]+\ln[r(n_1,n_2)] \quad (14)$$

The LPF and the HPF are applied to log [f_LL (n_1, n_2)] to separate the illumination component I and the reflectance component R, respectively, for each pixel value in the form of matrices. The SVD is performed on the (R matrix).

$$R=USV^T \quad (15)$$

The watermark (W matrix) is added to the SVs of the reflectance matrix.

$$D=S+kW \quad (16)$$

The SVD is performed on the new modified matrix (D matrix).

$$D=U_wS_wV^T_w \quad (17)$$

The sub-image (R_w matrix) is obtained by using the modified matrix (S_w matrix)

$$R_w=US_wV^T \quad (18)$$

An inverse homomorphic transform is performed on I and R_w to obtain a matrix X_w

$$X_w=R_w+I \quad (19)$$

The sub-band (LL) of watermarked image can obtained as

$$F\_LL_w = \exp\ (X_w) \quad (20)$$

So watermarked image can obtained by reconnect colors (Red, Green, Blue) then applying the inverse DWT to produce watermarked image F_w.

To extract the possibly corrupted watermark from the possibly distorted watermarked image, given U, S_w, V matrices and the possibly distorted sub-image F_w, the above steps are reversed as follows:

The homomorphic transform is performed on the sub-band (LL) for watermarked image f_LL_w

The HPF is used to get the possibly corrupted reflectance component R^*_w.

The SVD is performed on the R^*_w matrix.

$$R^*_w=U^*S^*_wV^{*T} \quad (21)$$

The matrix that includes the watermark is computed.

$$D^*=U_wS^*_wV^T_w \quad (22)$$

The possibly corrupted watermark is obtained.

$$W^*= (D^*-S)/k \quad (23)$$

The proposed technique's embedding algorithm is shown in figure 3 and extracting algorithm is shown in figure 4.

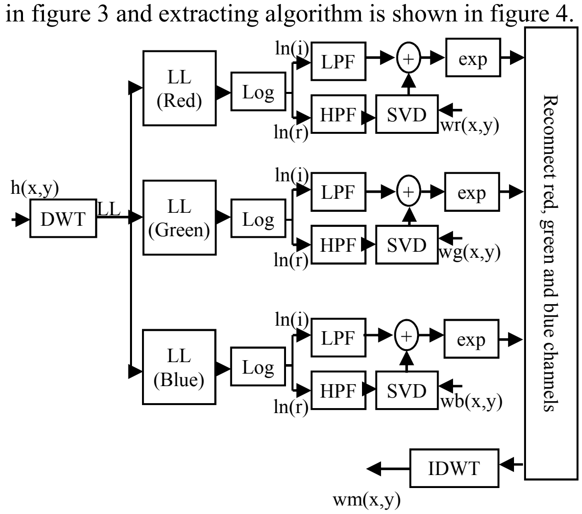


Figure 3. The embedding algorithm.

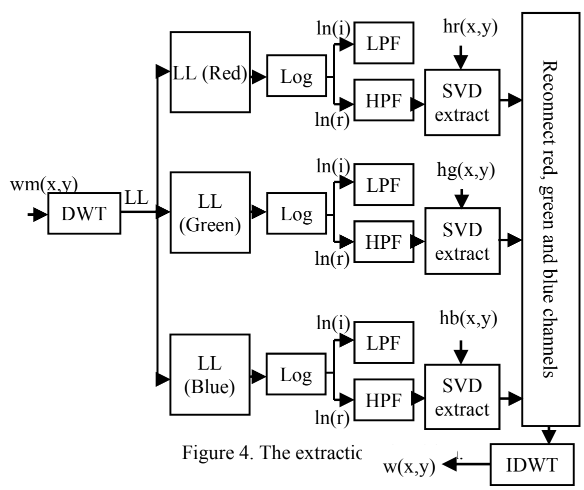
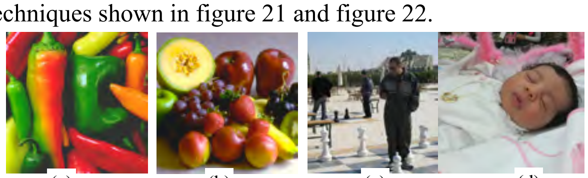


Figure 4. The extractic

5. Simulation Results

There are two experiments for each technique one using RGB color JPEG images with size 512×512, resolution 72×72 dpi and bit depth 24 host image pepper and watermark fruits, and the other test using RGB color JPEG images with size 512×512, resolution 180×180 dpi and bit depth 24 host image Khalid and watermark Rokayya as shown in figure 5 where (a) host image pepper, (b) watermark image fruits, (c) host image Khalid and (d) watermark image Rokayya. Visualization test results for

proposed technique compared with the other state of art techniques that stated in literature review without attacks are shown in figure 6. Figure 7 shows the rotate 30° attacks. Rotate 45° attacks are shown in figure 8. Figure 9 shows the rotate 60° attacks. Gaussian noise attacks with variance parameter 0.01 are shown in figure 10. Figure 11 shows the Gaussian noise attacks with variance parameter 0.05. Gaussian noise attacks with variance parameter 0.1 are shown in figure 12. Figure 13 shows the resize to 256×256 attacks then resize to 512×512. Motion blur attacks are shown in figure 14. Figure 15 shows the disk blur attacks. Average blur attacks are shown in figure 16, Figure 17 shows the JPEG compression 20% attacks. JPEG compression 40% attacks are shown in figure 18. Figure 19 shows the JPEG compression 60% attacks. Crop attacks are shown in figure 20. Table 1 and table 2 shows the evaluation matrices results (PSNR and NC) without attacks and algorithm CPU time for the proposed technique compared with the other state of art techniques. The NC for extracted watermark after attacks for the proposed technique compared with the other state of art techniques shown in figure 21 and figure 22.



(a) (b) (c) (d)

Figure 5. (a) host image pepper, (b) watermark fruits, (c) host image Khalid, (d) watermark Rokaya.

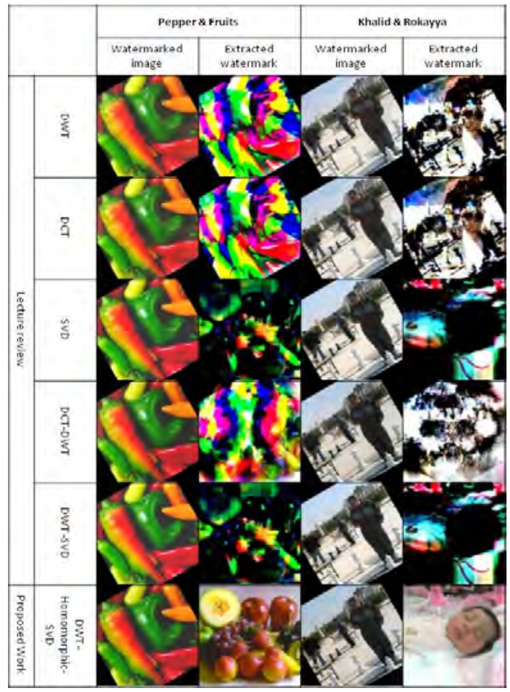


Figure 7. Visualization tests after rotate 30° attacks.

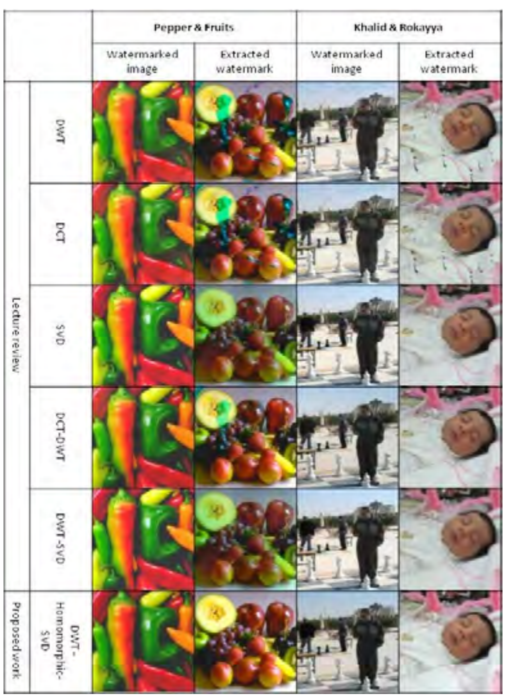


Figure 6. Visualization tests without any attacks.

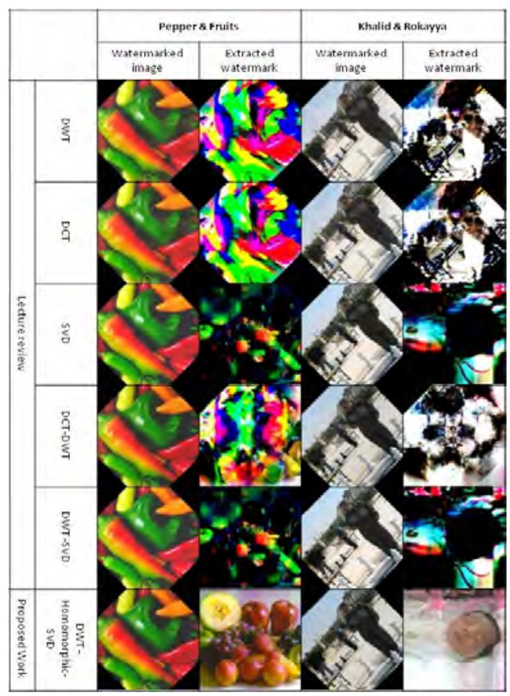


Figure 8. Visualization tests after rotate 45° attacks.

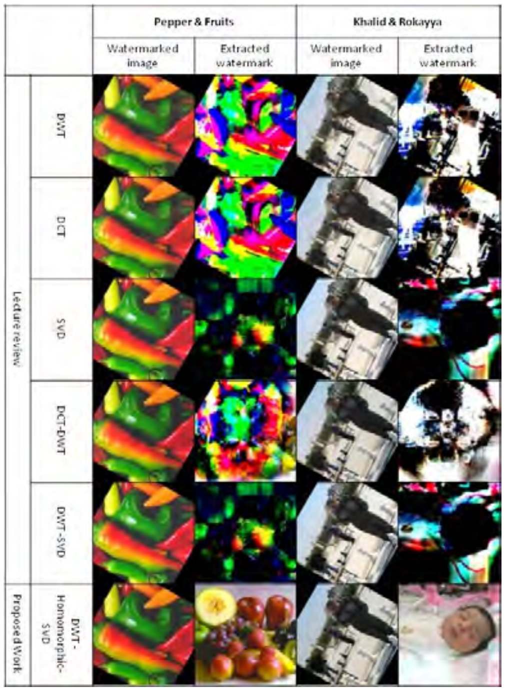


Figure 9. Visualization tests after rotate 60° attacks.

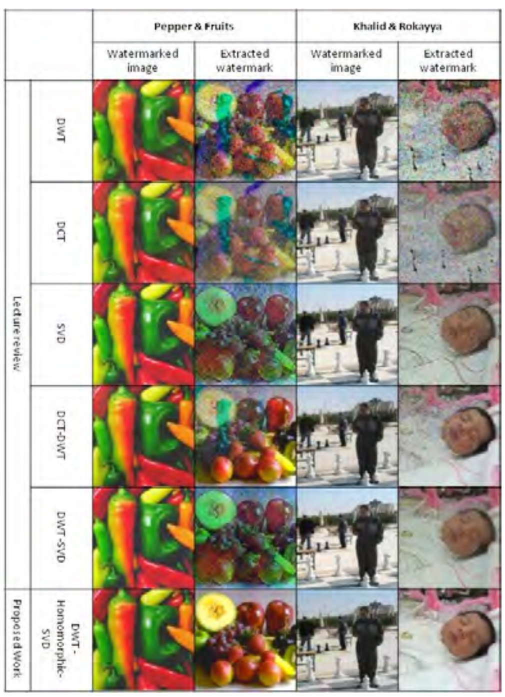


Figure 10. Visualization tests after Gaussian noise attacks with variance parameter 0.01.

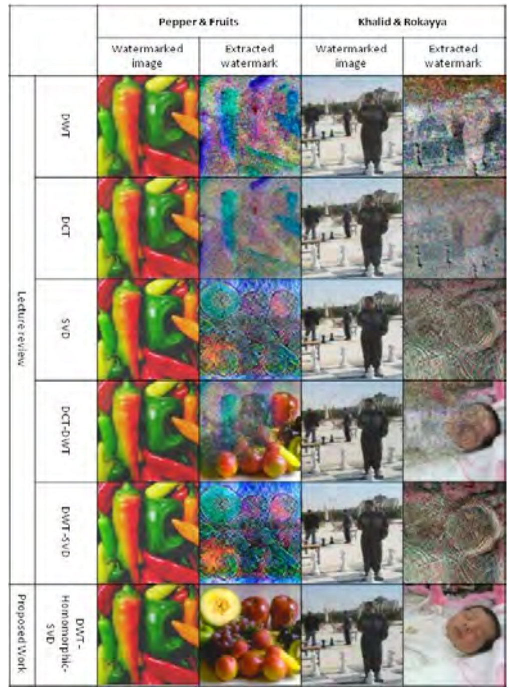


Figure 11. Visualization tests after Gaussian noise attacks with variance parameter 0.05.

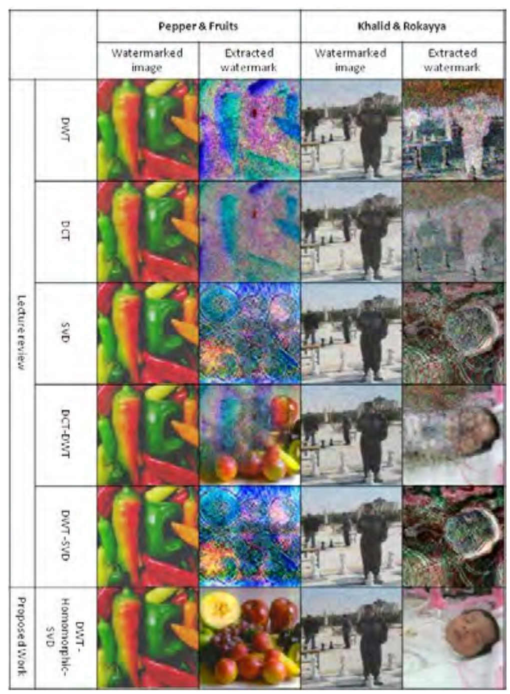


Figure 12. Visualization tests after Gaussian noise attacks with variance parameter 0.1.

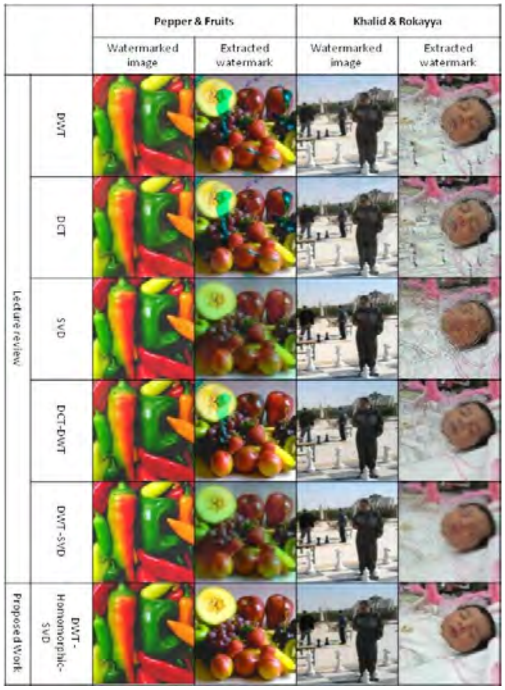


Figure 13. Visualization tests after resize to 256×256 then resize to 512×512 attacks.

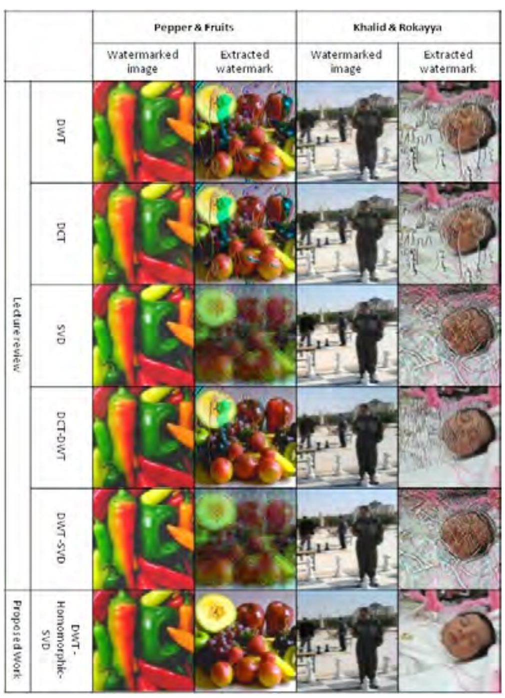


Figure 14. Visualization tests after motion blur attacks.

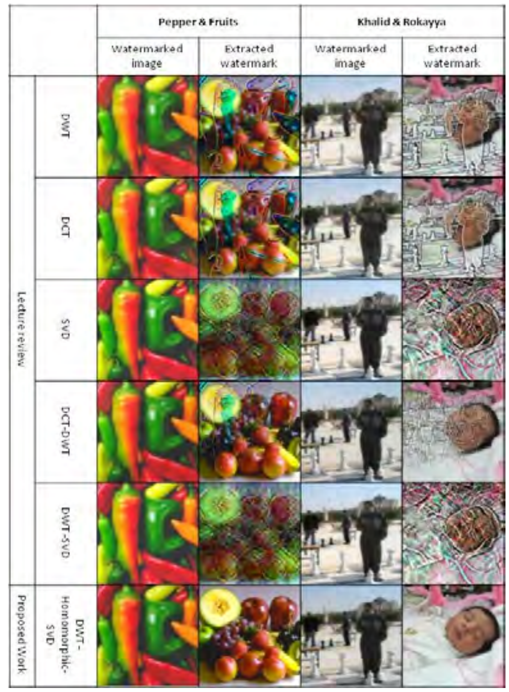


Figure 15. Visualization tests after disk blur attacks.

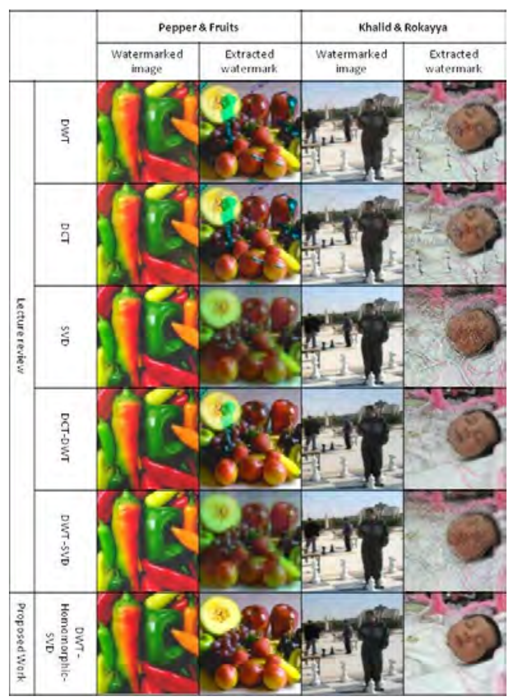


Figure 16. Visualization tests after average blur attacks.

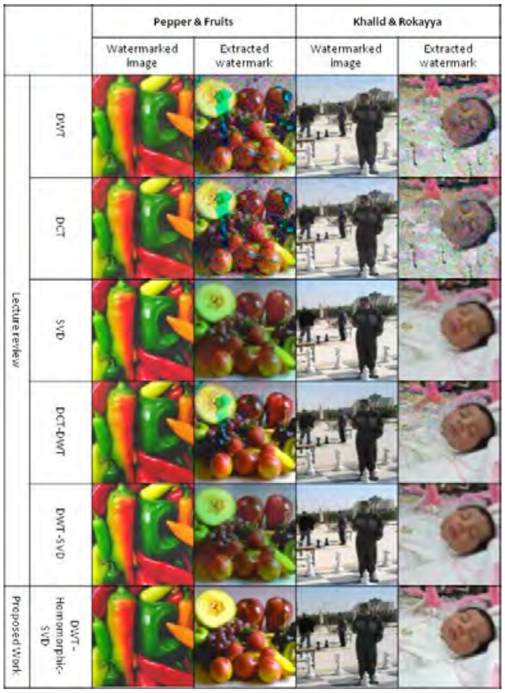


Figure 17. Visualization tests after JPEG compression 20% attacks.

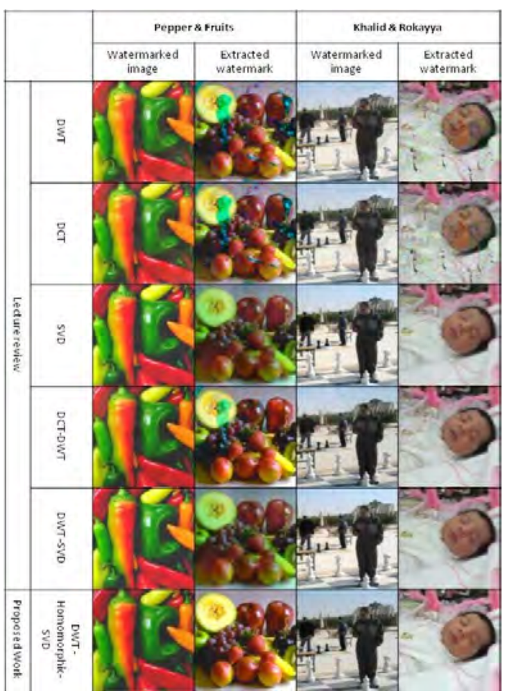


Figure 18. Visualization tests after JPEG compression 40% attacks.

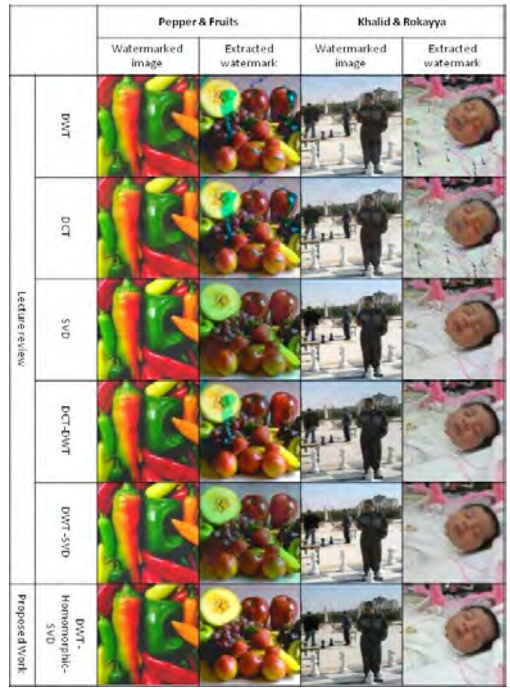


Figure 19. Visualization tests after JPEG compression 60% attacks.

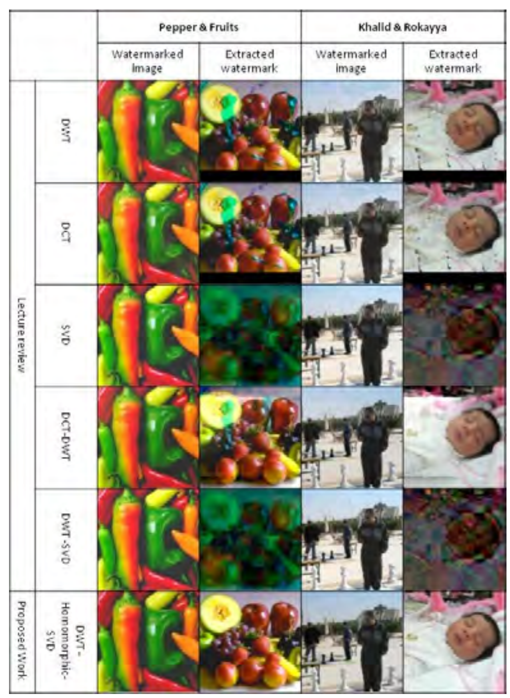


Figure 20. Visualization tests after crop attacks.

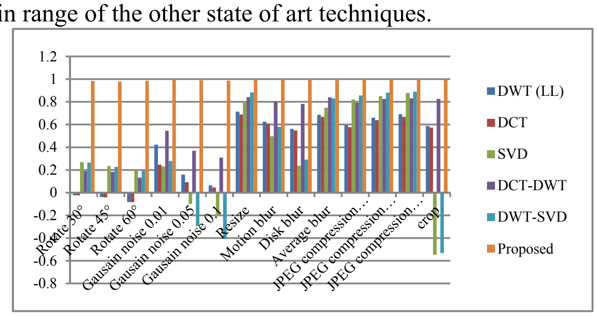
Table 1. The proposed watermarking technique compared with other state of arts techniques based on PSNR for watermarked image, NC for extracted watermark without attacks and CPU time for embedding algorithm for pepper and fruits images.

	DWT	DCT	SVD	DCT-DWT	DWT-SVD	Proposed
PSNR red	24.716	24.727	25.615	28.969	25.620	35.856
PSNR green	25.826	25.838	26.176	29.284	26.187	38.479
PSNR blue	27.676	27.688	28.222	31.376	28.229	34.896
NC red	0.7316	0.7107	0.9115	0.5896	0.9124	0.9963
NC green	0.9673	0.9364	0.9924	0.9785	0.9943	0.9980
NC blue	0.9145	0.8861	0.9594	0.9541	0.9634	0.9945
CPU time	1.4040	0.8424	3.8844	1.0140	2.5584	3.1044

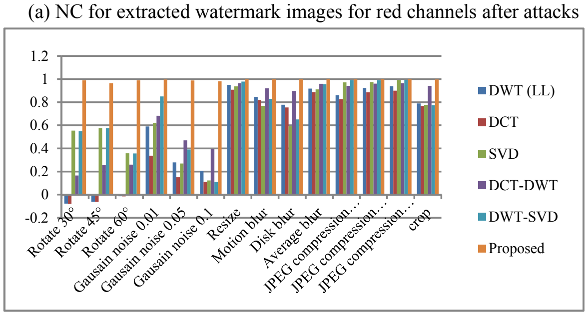
Table 2. The proposed watermarking technique compared with other state of arts techniques based on PSNR for watermarked image, NC for extracted watermark without attacks and CPU time for embedding algorithm for Khalid and Rokayya images.

	DWT	DCT	SVD	DCT-DWT	DWT-SVD	Proposed
PSNR red	22.902	22.919	22.944	28.234	22.939	33.301
PSNR green	23.322	23.344	23.388	29.011	23.391	33.793
PSNR blue	23.304	23.331	23.324	28.618	23.325	32.737
NC red	0.8876	0.7207	0.9955	0.8942	0.9954	0.9976
NC green	0.9394	0.7870	0.9980	0.9267	0.9980	0.9987
NC blue	0.9025	0.7742	0.9978	0.9219	0.9978	0.9985
CPU time	1.5288	0.7956	3.8064	1.0296	2.8236	3.1200

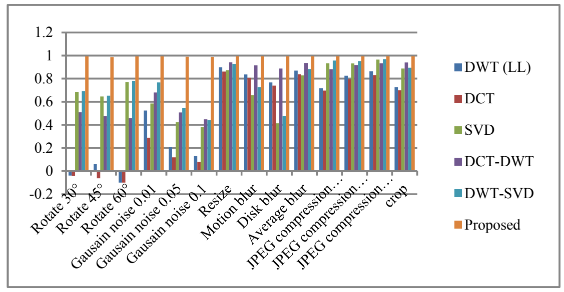
As shown from visualization test and experimental results, by visual inspection, the results reveal that no noticeable variations exist between the watermarked and the original images which enforce the fidelity of the proposed watermarking technique. The watermarked images and the extracted watermarks for the proposed watermarking technique have a high PSNR, NC respectively compared with the other state of art techniques in the three color channels. The embedding algorithm CPU time for the proposed technique is higher with few seconds than the other hybrid techniques but it is little speed than the SVD techniques. So the CPU time for the proposed technique is in range of the other state of art techniques.



(a) NC for extracted watermark images for red channels after attacks

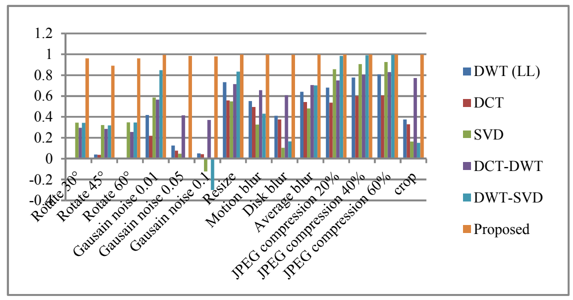


(b) NC for extracted watermark images for green channels after attacks

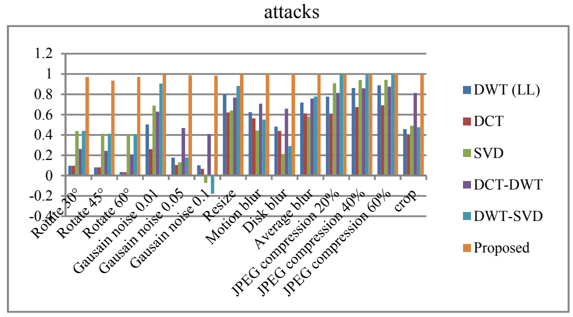


(c) NC for extracted watermark images for blue channels after attacks

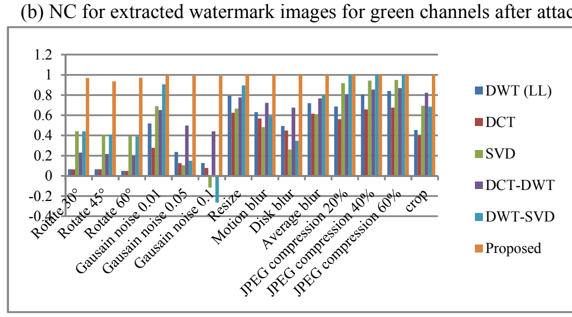
Figure 21. The proposed watermarking technique compared with other state of arts techniques for pepper and fruits images based on NC for extracted watermark after attacks



(a) NC for extracted watermark images for red channels after attacks



(b) NC for extracted watermark images for green channels after attacks



(c) NC for extracted watermark images for blue channels after attacks

Figure 22. The proposed watermarking technique compared with other state of arts techniques for Khalid and Rokayya images based on PSNR for watermarked image, NC for extracted watermark after attacks

As shown from visualization test, experimental results and evaluation figures after attacks, results illustrate that the extracted watermarks for the proposed watermarking technique have a high NC compared with the other state of art techniques in the three color channels, which guarantees watermarking existence. The NC for the extracted watermarks for the proposed technique is higher compared with the other state of art techniques in the three color channels. It means that the proposed technique is more robust against attacks.

6. Conclusions

This paper proposes an image watermarking hybrid technique using the DWT-homomorphic based SVD technique. It embeds the watermark during applying the SVD on the reflectance components of the sub-band LL by utilizing the DWT to divide the image into non-overlapping bands. The reflectance components of the sub-band LL is extracted using the homomorphic transform for each color (red, green and blue). It is shown that we can embed an RGB color image watermark to an RGB color host image with the same size. The experimental results demonstrated that the DWT-homomorphic based SVD watermarking has a high fidelity and robustness in the presence of different types of attacks. There is always a large probability for watermark detection. The embedding algorithm CPU time is in range of the other hybrid techniques. The achieved results also reveal the superiority of the proposed DWT-homomorphic based SVD watermarking technique over other state of art watermarking techniques.

7. References

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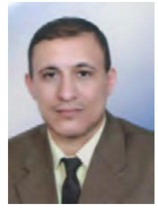

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